A CRYSTAL CALIBRATOR UNIT

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Introduction

A crystal-controlled calibrator—or marker as it is sometimes called—having outputs at known frequency steps, is a useful piece of test equipment in the shack. As well as being used to set the tuning dial on receivers with analogue readout, and to give confidence that all is well with digital readout receivers, a calibrator can be used to calibrate transmitters and transceivers. Another use is in checking the stability of oscillators. Some details of these applications are given later.

The calibrator included in this unit produces outputs at harmonics of 10kHz, 100kHz or 1MHz, depending on the setting of a front-panel-mounted switch. Harmonics extending into the vhf region are present in the output waveform.

Other useful functions can be included into a calibrator unit at relatively little extra cost. Those incorporated into this unit are first, a ttl-compatible clock output at selectable frequencies from 1MHz down to 1kHz, and, second, an accurate 1kHz pure sine wave output. This output can be used for distortion testing of amplifiers, or as a general-purpose sine-wave source. These extra facilities can be omitted if not required, without affecting the operation of the basic calibrator.

Circuit operation (Fig 1)

A 1MHz crystal-controlled oscillator is formed by IC1c and associated components. R1 biases the inputs of this gate so that it acts as a linear amplifier, sustaining the oscillation. The exact frequency of oscillation of the crystal can be trimmed by adjusting C21. The output from IC1c is buffered by IC1d which drives the CLOCKA input of the 4518B dual decade counter IC2. By connecting the Q4A output to the ENABLEB input, the two divide-by-ten stages of IC2 are connected in series and the overall division ratio is 100. The Q4B output of IC2 drives the CLOCKA input of IC3, another 4518B, of which only one decade divider stage is used.

Six outputs from IC2 and IC3, as well as the 1MHz output from IC1d,

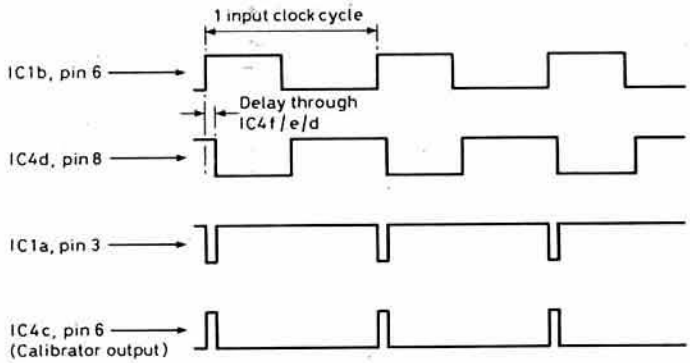

Fig 2. Timing diagram of narrow pulse generator (timing delay exaggerated)

are connected to S1. This allows any one of these signals to be selected and buffered by IC4a. The pull-down resistor R3 on the input to IC4a prevents this input from floating, with the possibility of damage, while S1 is between positions. The output of IC4a is connected to a front panel socket, SK1, and provides a ttl-compatible output at 1MHz and 500, 100, 50, 10, 5 or 1kHz depending on the setting of S1.

The 1MHz, 100 and 10kHz outputs from IC2 and IC3 are selectable by S2 which feeds the input to IC1b. This gate drives the narrow pulse generator IC4f/e/d/IC1a. A timing diagram illustrating the operation of this circuit is shown in Fig 2. Basically, a clock signal and its delayed inverse are fed to the two-input NAND gate IC1a which produces a logic 0 following each positive edge of the original clock signal. This circuit can be thought of as a digital monostable, producing a fixed length output after being triggered by a clock edge. It is because of the speed requirement of this part of the calibrator unit that HC or HCT devices must be used for IC1 and IC4. These high-speed cmos devices produce narrow width (typically 20ns) logic 0 pulses with fast edges at the output of IC1a. The output of IC1a is inverted by IC4c which drives SK2, the calibrator output, via a dc blocking capacitor, C20.

The Q3A output of IC3, which also runs at 1kHz, is buffered by IC4b and feeds the filter driver operational amplifier stage, IC5. This Q3A output from IC3 was chosen because it has a mark:space ratio closer to 1:1 and therefore contains a smaller second harmonic content than Q4A. C7 acts as a dc blocking capacitor, and the network R4/C8/R5 attenuates the high frequencies present in the 1kHz square wave.

C12, C13, C14, C15, L1, L2 and L3 form a seven-pole Chebyshev lowpass filter. The cut-off frequency has been set to approximately 1,200Hz to prevent the possibility of higher-than-desired attenuation at 1kHz, due to component tolerances, had the theoretical cut-off been set to exactly 1kHz. The input and output impedance of the filter is 470Ω, and this is provided on the input by R11. The output is left unterminated, resulting in more passband ripple than calculated, but this is immaterial in this application. This results in a better stopband response, which is exactly what we need here.

RV1 allows the output level taken from the filter to be varied and feeds the output buffer stage, IC6. This stage provides a voltage gain of one, and has a low output impedance to drive external circuits via SK3, the 1kHz sine output. A low-noise, low-distortion device such as the TL071 specified should be used for IC6 if the purity of the output waveform is to be preserved. Actual measurements on the prototype have shown the 2kHz component to be −75dB and the 3kHz component to be −55dB with respect to the 1kHz level. A maximum output level of approximately 3·5V peak-to-peak is available, and this can be increased if desired by increasing the value of the feedback resistor R16.

IC7 produces the +5V rail for all the logic. Although IC2 and IC3, being 4000B-series devices, can operate from rails as high as 15V, the HC/HCT devices, IC1 and IC4, have an upper limit of 6V. The unit is intended to be powered via SK4 and SK5 from an external power source. However, the total current consumption at 12V is only about 10mA and so internal batteries could be used.

Building the unit

The etching pattern of the pcb is shown in Fig 3. I have deliberately not cramped the component and track spacings so that the pcb can be reproduced easily by hand using an etch-resist pen.

Fig 4 shows the positioning of the components on the pcb. IC sockets can be used to mount IC1-6; these can be very helpful during testing, allowing a suspect ic to be removed without fear of damaging it or the pcb. Since all the digital ics used are cmos devices and the operational amplifiers have jfet inputs, take the normal anti-static handling precautions and ensure that your soldering iron is earthed. The links required on the board can be made from bare wire, as their spacing means there is no danger of adjacent links shorting together.

On the prototype, X1 was soldered into the board, but a holder can be

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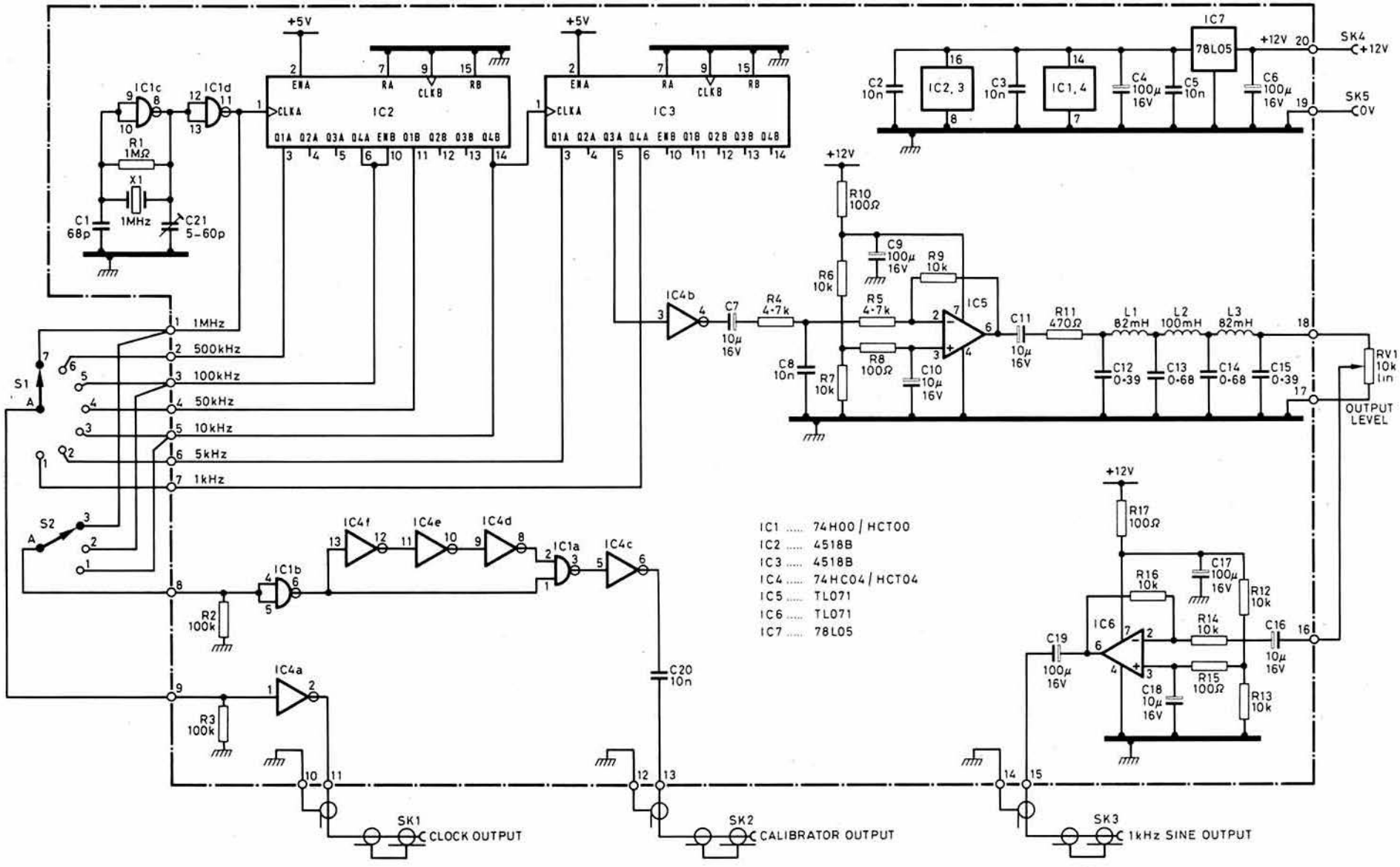


Fig 1. Calibrator unit circuit diagram. Note that pin 10 of IC3 should be connected to ground

used. If you do solder it directly, take care to complete the job as quickly as possible.

On the prototype, 1mm solder terminals were used for the 20 external connections to the board. These give a neat finish and allow connections to be soldered and unsoldered without having to remove the board from its mountings to get access to its underside.

The prototype unit was housed in an aluminium case type J9, available from Minffordd Engineering, but any suitable case which is to hand can be used. No detailed case drilling information is given here, but suggested positions of the major components is shown in Fig 5. It is best to obtain all the components which are to be mounted in the case, including the pcb, *before* drilling any holes so that the hole diameters and centres can be checked first. Unless you have a large drill available, the holes for the switches, sockets and RV1 will probably have to be finished with a round file or tapered reamer.

Output sockets other than the BNC ones specified can be used if they are more convenient for your set-up. No attempt is being made to match impedances at the outputs, so do not worry about this aspect.

There is sufficient room at the left-hand side of the pcb to mount a battery holder if desired. The prototype unit worked down to 7V, so a holder for six AA-size batteries (giving nominally 9V) could be used and would give long life if used intermittently. An on/off switch would also need to be fitted, and it could be mounted on the rear panel instead of SK4 and SK5.

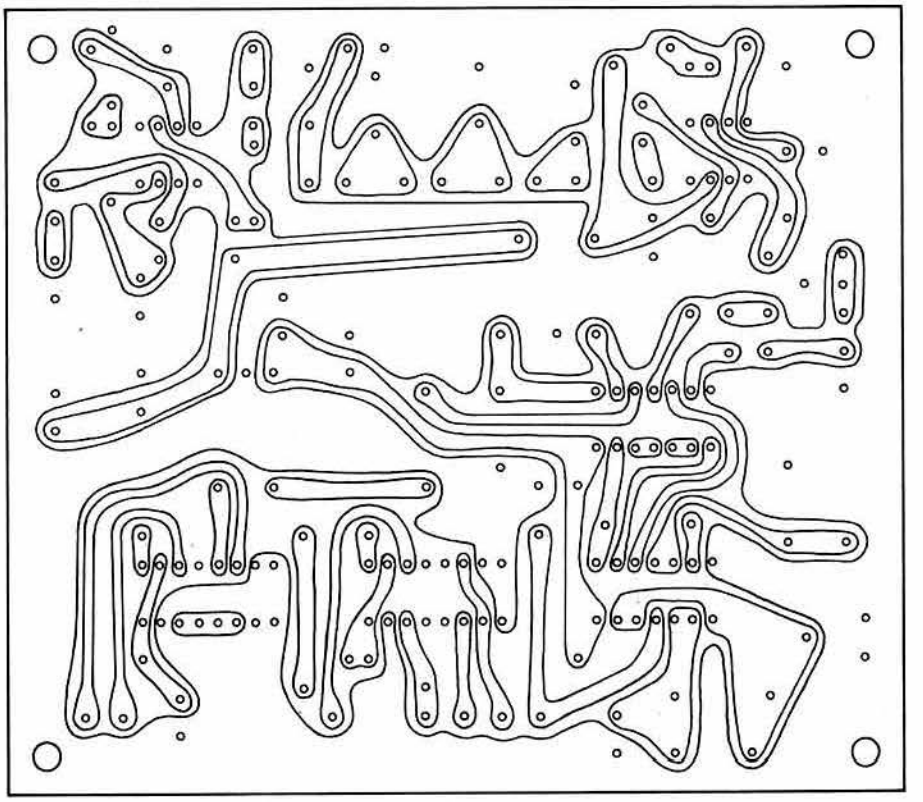


Fig 3. PCB tracking

Testing

Before applying power to the unit, a careful visual inspection should be made, looking for solder bridges on the pcb, checking the value and orientation of each component, and checking the wiring to the controls and sockets. If all is well the power can be switched on and the supply current measured if a milliammeter is available; this should be approximately 10mA—if it is much more than this, switch off quickly and re-check everything.

If an oscilloscope is available, the crystal oscillator can now be checked, monitoring the outputs of IC1c and IC1d; a square wave of 5V amplitude should be seen. Now move along the outputs of IC2 and IC3, verifying that the correct frequency outputs are being produced. To complete the testing of the clock generator components and wiring, monitor SK1 and check that the correct frequency output is produced for each setting of S1.

Now monitor the input of IC1b and check that 10 or 100kHz or 1MHz is present as S2 is rotated. The inputs to IC1a can be checked to see that they appear to be the inverse of each other if a dual-beam oscilloscope is to hand. Unless the oscilloscope is of high quality, the slight delay of one input with respect to the other will probably not be seen. Similarly, an oscilloscope with a relatively low bandwidth will not show much of the narrow pulses at the outputs of IC1a, IC4c and SK2.

The 1kHz sine wave circuitry can now be checked. Monitor the output of IC4b and check that a 1kHz rectangular waveform is present. Now move to the output of the filter, or the top end of RV1, and check for a sine wave. Finally, move to SK3 and check that an undistorted sine wave, whose amplitude can be varied by RV1, can be seen. The maximum amplitude here should be approximately 3·5V peak-to-peak.

Now that the unit is fully functional, C21 can be adjusted to set the oscillator to as close to 1MHz as possible. If a frequency counter of known accuracy is available, this is simple. An alternative is to use a receiver tuned to a standard frequency transmission such as MSF Rugby on 2·5MHz, 5MHz or 10MHz.

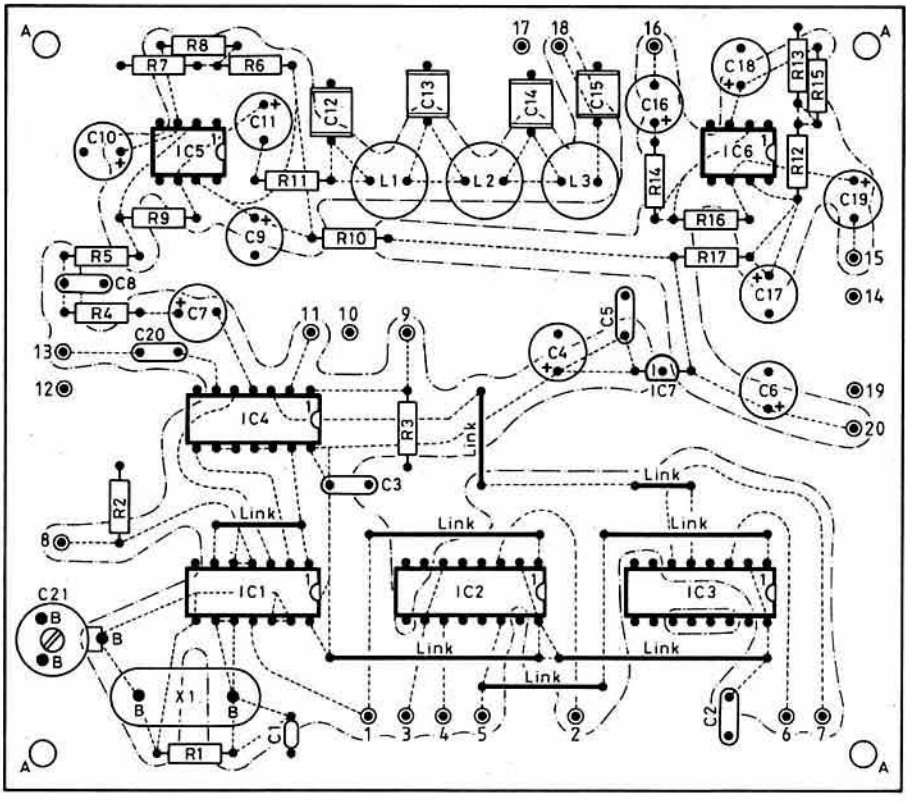
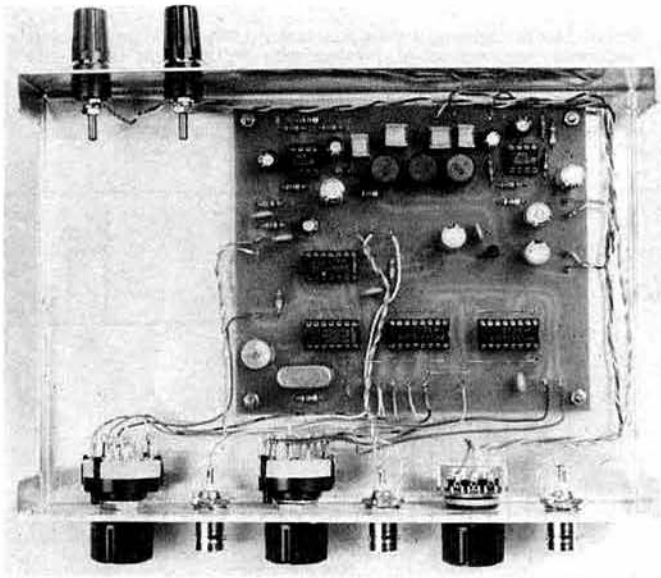


Fig 4. PCB component layout

The MSF transmissions consist of a continuous carrier, amplitude modulated with short bursts of 1kHz at 1s intervals for the 5min following each multiple of 10min. Use the S-meter on your receiver to tune in the signal accurately. Now switch the calibrator unit to 100kHz, connect it to the receiver, switch the bfo on, and adjust C21 for zero beat. This is all that is needed; the other ranges will automatically be accurately set as they are all derived from the same crystal oscillator.



Interior view of the crystal calibrator

Using the unit

Checking the dial setting of a receiver should be carried out by attaching a short length of wire to the calibrator output (SK2) and placing it close to the receiver's antenna socket. This should give sufficient coupling to enable the marker frequencies to be heard. A direct connection to the antenna socket can be made if necessary. The receiver's bfo should, of course, be turned on for the markers to produce an audio output. If the receiver is already in reasonable calibration it should be possible to use the 10kHz setting of S2 to make a fine adjustment to the receiver. The receiver's manual should be consulted on how to make this adjustment: do not be tempted to start twiddling trimmers and cores without knowing exactly what you are doing! A receiver further out of calibration might require an initial marker spacing of 100kHz or even 1MHz to locate a known initial dial setting.

As the calibrator output is switched between the 10, 100kHz and 1MHz settings, the markers will be found to get stronger. This is what would be expected, as the width of the output pulses always remains constant, but on the 10kHz setting they contain 10 times as many discrete frequencies as on the 100kHz setting. The energy content of each frequency component would therefore be expected to be lower at the 10kHz setting. A similar argument is true for the 100kHz setting with respect to the 1MHz setting.

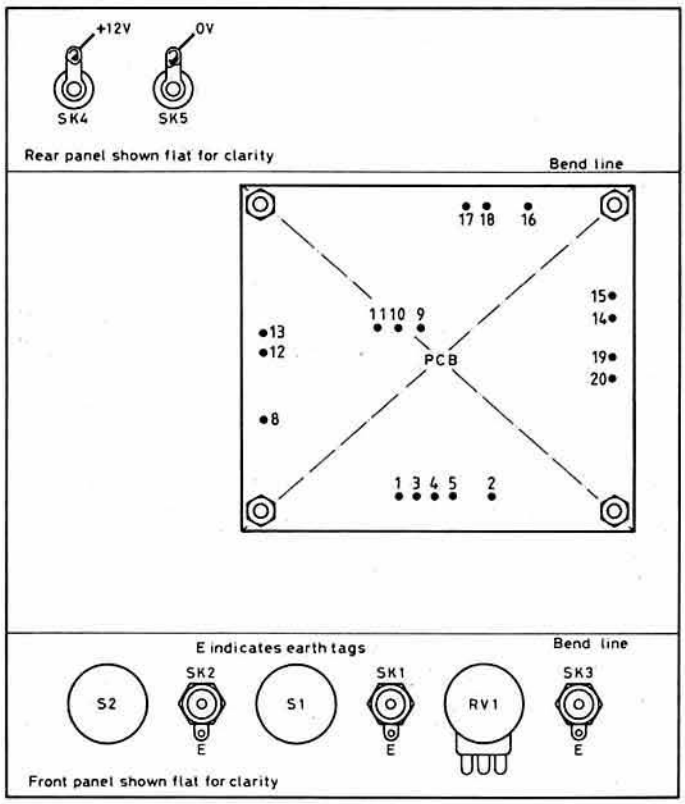


Fig 5. Component placement in case

A newly-built receiver, completely uncalibrated, is best calibrated by initially locating a known frequency signal, such as an RSGB news broadcast on about 3,650kHz. Using the calibrator on the 100kHz setting, the receiver is then tuned lower in frequency until the 3·6MHz point is located. This is marked on the dial. The other 100kHz points within the band can then be located and marked, before the calibrator is switched to 10kHz to mark the dial at finer intervals.

When checking a transmitter, the signal from the transmitter is first tuned in on a receiver, and the dial reading at which it is heard noted. Then the 10kHz-spaced marker frequencies above and below this reading are tuned in and noted. The transmitter frequency obviously lies between these two known frequencies.

When the receiver and transmitter are combined in a transceiver, the above method cannot be used, as the receive and transmit sections cannot be used simultaneously. However, since the receive and transmit frequencies should be the same, it is only necessary to calibrate the receiver section as described above.

Since the calibrator output is crystal-controlled, and therefore, very stable, it can be used to check the stability of the oscillator(s) in, say, a receiver. This can be done by tuning the receiver to approximately 1kHz from a marker and then assessing how much the audio beat frequency changes with time, either by ear or by connecting a frequency counter to the receiver's audio output. This method has several advantages: first, the receiver can be checked without having to get access to its oscillator output which could in itself affect stability; and second, the covers of the receiver do not have to be removed, which again could affect stability due to draughts.

The clock output from SK1 is intended as a general purpose ttl, or cmos operating from 5V compatible signal source. It can be used, for example, to supply a clock to a digital circuit under development before the clock source built into the circuit itself is constructed or working. Although only seven different frequencies are selectable by S1 as built into the prototype,

Components list

R1	1MΩ
R2, 3	100kΩ
R4, 5	4·7kΩ
R6, 7, 9, 12, 13, 14, 16	10kΩ
R8, 10, 15, 17	100Ω
R11	470Ω
All resistors are 0·25w 5% carbon	
RV1	10kΩ linear carbon pot
C1	68pF ceramic plate
C2, 3, 5, 8, 20	10nF disc ceramic
C4, 6, 9, 17, 19	100μF 16V radial electrolytic
C7, 10, 11, 16, 18	10μF 16V radial electrolytic
C12, 15	0·39μF polyester Siemens type
C13, 14	0·68μF polyester Siemens type
C21	5-60pF foil trimmer
L1, 3	82mH Toko Type 10RB
L2	100mH Toko Type 10RB
X1	1MHz HC33U crystal
IC1	74HC00 or 74HCT00
IC2, 3	4518B
IC4	74HC04 or 74HCT04
IC5, 6	TL071
IC7	78L05
S1	Single-pole seven-way rotary (use a 12-way switch)
S2	Single-pole three-way rotary
SK1, 2, 3	Chassis-mounted BNC sockets
SK4, 5	4mm insulated terminals, red and black

Miscellaneous
PCB (see text).
IC sockets (two 16-pin, two 14-pin, two 8-pin) if required.
Case (type J9, available from Minffordd Engineering, Sun Street, Ffestiniog, Gwynedd; or similar).
Knobs for S1, S2 and RV1.
1mm terminal pins 20 off.
6BA screws, nuts.
Connecting wire.

more can be added if required. The following outputs from IC2 and IC3 have alternative frequencies available:

IC2 Q2A (pin 4).....200kHz	IC3 Q2B (pin 12).....200Hz
IC2 Q2B (pin 12).....20kHz	IC3 Q3B (pin 13).....100Hz
IC3 Q2A (pin 4).....2kHz	IC3 Q4B (pin 14).....50Hz
IC3 Q1B (pin 11).....500Hz	

Simultaneous outputs can be taken from IC2 and IC3 if required.

One application of the 1kHz sine wave output is in the testing of audio amplifiers. This output, set to a low level, is connected to the input of the amplifier under test and traced through the circuit, watching for possible distortion. If any is found then because the source is undistorted, it must be due to a fault in the circuit under test. If the output stage of the amplifier is Class B, requiring the quiescent current to be set, monitor the output with an oscilloscope while adjusting the potentiometer which controls the quiescent current. As the current is reduced, a level will be found where cross-over distortion is evident. Increase the quiescent current a little, making the distortion disappear, and you can be confident that the quiescent current is set as low as possible while keeping distortion low as well.

APPENDIX. Ideal calibrator waveform

This section gives some theoretical background to the type of waveform useful for calibration purposes. Many designers recognize that a square wave like that shown in Fig A1(*a*) contains many harmonics of the fundamental frequency, and so is useful as a calibrator output. The use of a 1:1 mark/space ratio waveform, however, has its drawbacks, as theoretically it contains only the odd harmonics of the fundamental frequency. Fourier analysis of a perfectly 1:1 mark/space ratio square wave gives the frequency spectrum as:

$$f(t) = k\left[\cos(wt) - \frac{\cos(3wt)}{3} + \frac{\cos(5wt)}{5} - \ldots\right]$$

where k is a constant whose value depends on the peak voltage of the square wave. This expression uses cos(wt) to indicate a sine wave at the fundamental frequency, cos(3wt) for a sine wave at three times the fundamental, and so on. Remember that a cosine wave is just a sine wave shifted by 90°. Note that only terms such as cos(wt), cos(3wt) etc, are present, and no even harmonics are present at all. This spectrum is shown in Fig A1(*b*), and the gradual reduction in the amplitude of successive components can be seen.

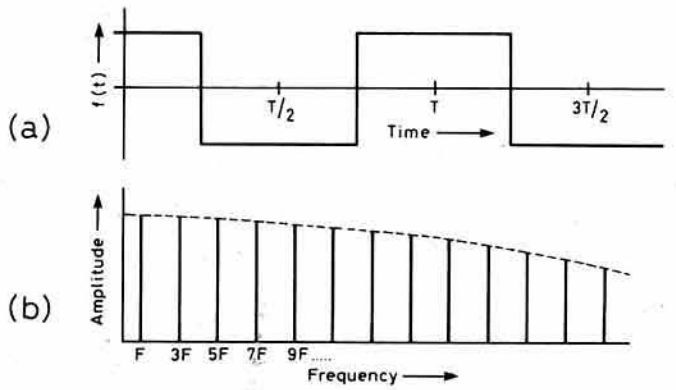


Fig A1. (*a*) 1:1 mark; space ratio square wave. (*b*) Frequency spectrum of (*a*) waveform

Fig A2(*a*) shows a waveform which does not have a 1:1 mark/space ratio, consisting of rectangluar pulses of duration τ seconds and repetition time T seconds. The frequency spectrum of this waveform is more complex than the previous example and is given by:

$$f(t) = k1 + k2\left[\cos(wt).\frac{\sin(\pi/k3)}{\pi/k3} + \cos(2wt).\frac{\sin(2\pi/k3)}{2\pi/k3} + \ldots\right]$$

where k1, k2 and k3 are constants. A plot of this spectrum is shown in Fig A2(*b*). Note here, first, that all the cosine terms (of wt, 2wt, 3wt etc) are present, and second, that the amplitudes of these terms follow a sinx/x type of sequence.

One characteristic of this sinx/x sequence is that its value is zero at multiples of the frequency equal to $1/\tau$ Hz. So if the pulse duration is 100ns, the zeros will be at 10MHz, 20MHz and so on: if the pulse duration is 10ns the zeros will be at 100MHz, 200MHz and so on. If one of these zeros happens to correspond to a harmonic of the repetition frequency, that harmonic will not be present.

It can be seen that as the duration of the pulses in the waveform becomes shorter with respect to the repetition frequency, the amplitude terms become smaller more slowly, and so the frequency harmonics are more equal in amplitude. If the pulses in the waveform were infinitely thin, all the harmonics would be equal in amplitude because the first zero in the sinx/x envelope would be at infinity.

The ideal output waveform from a calibrator consists, therefore, of the narrowest possible pulses at the repetition frequency of the desired calibration spacing. How then do 1:1 mark/space ratio square wave designs manage to do their intended function, despite the arguments put forward above? The answer is that the square waves produced

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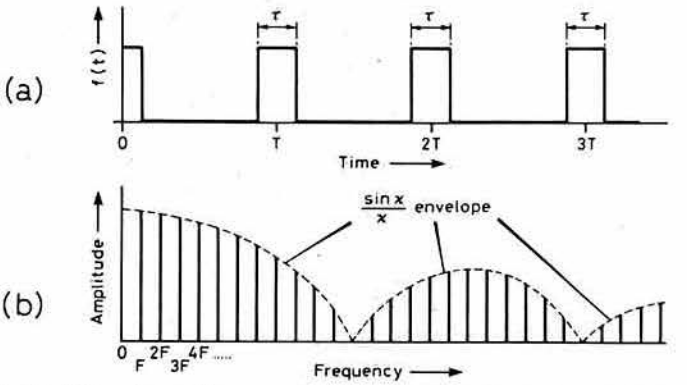

Fig A2. (*a*) Waveform with a non-1:1 mark/space ratio (*b*) Frequency spectrum of *a* waveform

are not of exactly 1:1 mark/space ratio, and a certain amount of differentiation must take place at the input to the receiver being calibrated. These effects generate the missing harmonics, and though they will be of much lower amplitude than the odd harmonics, they are sufficient to be detected by the receiver. □

BOOK REVIEW

Shortwave Listening Handbook, by Harry L Helms. First edition 1987. Published by Prentice-Hall Inc, 243 + X pages (228 by 145 mm). Hard covers. Price not listed with review copy.

Until recently, entry into amateur radio often stemmed from an initial interest in listening to the many shortwave broadcasting stations that have sprung-up all over the world since the pioneering days of Dr Frank Conrad of KDKA, W8XK. The "all-wave" and later "all-band" broadcast receivers usually covered only the 7 and 14MHz amateur bands, and even their limited capability of receiving amateur transmissions faded with the increasing use by amateurs of ssb rather than double-sideband a.m in the'fifties and 'sixties. One result is that the hobby of broadcast swling has developed on parallel rather than converging lines with amateur radio. Nowadays, with some reason, many amateurs regard hf broadcasting as a not-to-be-encouraged rival seeking to take over "our" frequencies, either legally through the ITU or, as in the case of 7·0 to 7·1MHz, purloined in disregard of the ITU Radio Regulations.

Yet the swls remain the natural recruiting ground. Their dedication in seeking out the odd low-power and "tropical band" broadcast stations often needs a familiarity with hf propagation, antennas and receivers as deep as that of the hf amateur.

This new American book (the author is also an Extra Class radio amateur) is an excellent and informative introduction to shortwave radio, how it works, what you can hear, how to select and use shortwave receivers etc. It provides extensive information on the main hf "external broadcasting" organizations and their facilities. Later chapters describe the "utility" communications services (which in the UK cannot legally be deliberately monitored). Less convincing are the author's attempts to add spice to sw listening by such chapters as "Unusual, illegal and mysterious radio activity". I cannot imagine anyone getting much satisfaction, for example, in listening to the East German "numbers" transmissions, even if these are intended for their agents in the West. Again, he is surely wrong in attributing the "first" clandestine ("black") broadcasting to the 1941 Russian-based "Radio Espana Independiente". Attempts to mislead the listener as to the location (and who controls) broadcast transmitters certainly goes back to the 'thirties when, for example, an anti-Nazi transmitter was operated illegally in Czechoslovakia by the Black Front until raided by undercover German agents. Even the UK began operating "black" transmitters built by "Pop" Gambier-Parry's (G2DV) engineers for the Political Warfare Executive in 1940. ("Das wahre Deutschland" from May 1940, with Romanian, French and Italian PWE "black" programmes later that year).

Nevertheless, in most respects this is a well-written, well-researched book for those whose receivers tune frequently or occasionally to the hf broadcast bands.

Contents: 1, What is shortwave listening? (20pp), 2, Understanding the shortwave spectrum (19pp), Selecting a shortwave receiver (20pp), 4, Antennas and accessories (22pp). 5, Radio propagation (17pp). 6, Major international shortwave broadcasters (28pp). 7, Domestic shortwave broadcasting (25pp), 8, Utility stations (16pp), 9, Other radio activities (21pp). 10, Unusual, illegal and mysterious radio activity (25pp), 11, The hobby of shortwave listening (15pp). Appendix 12pp. and three page index.

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